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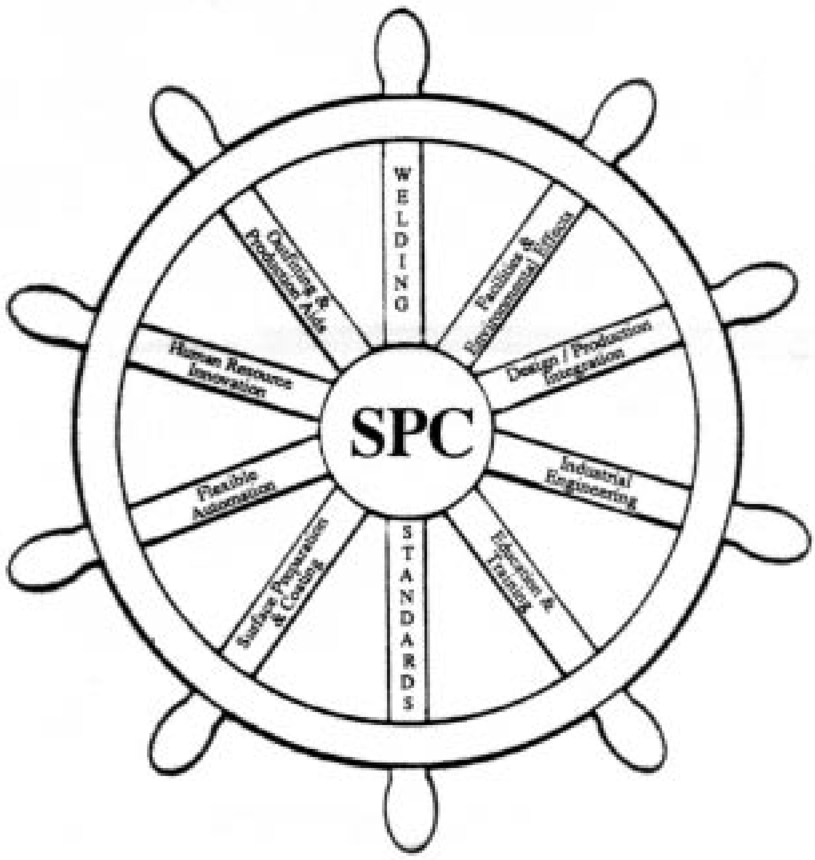

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Photogrammetry as an Advanced Planning Tool for Naval Shipyards

7B-1

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ABSTRACT

Photogrammetric technology captures dimensional data on systems' existing configurations. Photogrammetry is useful for determining the dimensional attributes of a system whose configuration has been modified and/or not recorded or updated. Knowing before execution of work begins the as-built structural conditions of systems on which work will be performed increases the shipyard's ability to plan a job efficiently, allowing the job to be completed in a timely cost effective manner. This can assure millions of dollars of elimination of rework and trial-and-error fit-ups and ensures enhanced product quality.

This paper will present several case studies in which naval shipyards have used photogrammetry prior to execution of work in order to effectively plan and accomplish the work more efficiently. Successes realized through the use of photogrammetric technology can be shared among all of the naval shipyards with great cost savings potential to the Navy.

BACKGROUND

Photogrammetric technology captures dimensional data on systems' existing configurations. Photogrammetric cameras are used on site to take pictures of the area of consideration with minimal disruption of the work force - most of the work is accomplished at the photogrammetric and CAD/CAM workstations. At the photogrammetric workstation, a measuring instrument is used to extract data from the photos, and a computer with photogrammetric software determines the dimensional data points. Resultant data can then be transferred to a CAD system to generate an engineered drawing. The data can either be two or three dimensional, and is not constrained by the complexity of the configuration. While Photogrammetrv is not a brand new, untried technology, many aspects of it have been automated to make it a fast, versatile, and accurate method of collecting dimensional data.

The extended uses for photogrammetry and its benefits are numerous. The following four categories represent diverse uses of photogrammetric technology:

1) Dimensional Attribute Determination. Photogrammetry is useful for determining the dimensional attributes of systems whose configurations have been modified and/or not recorded or updated. Photogrammetry can be used effectively to aid in producing needed drawings for parts where a part drawing is unavailable.

2) Structural Verification. Large scale naval ship repair or alteration jobs sometimes require tests to verify certain structural conditions. Collecting data necessary for measurements on a substantially sized component can be very labor intensive, costly, and subject to inaccuracies. Photogrammetry is an excellent tool for verifying structural conditions. The high degree of accuracy possible makes photogrammetric technology a very reliable method of obtaining precise measurements. As an example, Charleston Naval Shipyard has performed numerous tests to verify photogrammetry as a method for measuring full and partial submarine hull circularities.

3) Advance Planning Tool. One of the most important values in photogrammetry is in its use as an advance Planning tool. Knowinq before execution of work begins the as-built structural conditions of systems on which work will be performed increases the shipyards* ability to plan a job efficiently, allowing the job to be completed in a timely, cost effective manner. This can save millions in material and manpower by assuring

first time quality and the elimination of rework and trial-and-error fit-ups.

Photogrammetric technology as an advance planning tool would also be extremely valuable in the design of ship alterations. Planning yards that are responsible for developing implementation plans for major alterations during an availability could employ photogrammetric technology to identify ships' existing conditions in areas affected by the alteration, allowing increased pre-planning capabilities.

4) Information Source. In addition to definition of structural conditions, photogrammetry can also be useful in facilitating inspection procedures, and providing permanent records and historical backup data, often useful to check results, gather additional data at any time, or as informational data for technical or litigation issues.

The following case studies illustrate the varied applications afforded by the use of photogrammetric technology in naval shipyard repair and alteration projects.

DAVITS FABRICATION PROJECT

The use of photogrammetry to determine unknown dimensional attributes is an important application of photogrammetric technology.

Naval ships' components and compartments are often modified during overhaul and repair, but subsequent changes to the drawings are neglected: as a result "as-built" drawings are not indicative of "as is" conditions, making the planning and execution of work difficult and costly, and often resulting in hundreds of manhours of rework. Further many projects require the duplicate manufacture or repair of a system to which no documentation exists. Currently no method exists to capture the "as-is" condition of system configurations, other than costly and labor intensive manual measurements and redrafting.

In January 1988, Charleston Naval Shipyard was faced with this problem. DDG-45 whale boats' and DDG-39 personnel boats' original davits were determined to be made of the wrong material and had to be refabricated and replaced using proper material.

Old plans for the original davits dated back to 1956 from Welin Davit and Boat Division. Many critical changes had been made to the davit, but formal revisions and modifications to the original part drawings were neglected. These changes included additional designs not included on the original drawings like angle of trackway, shapes of heads, and additions such as tensioning devices, tension guides, tension sheeve supports, and stops. Therefore, complex angles and configurations, and sizes of other structures that had been added were unknown.

The first davit for the whale boat was recreated manually; sizes were extrapolated from templates created at the boat, and from davits removed from the boat and brought to the shop for comparison. This process was very time consuming; because the davits are very large, "tracing" templates was awkward, and templates were difficult to handle. Further, obtaining accurate dimensions was impeded by other structures that "stick out" in the way, (especially for angles, one to two degree accuracy is important). Finally, and most obviously, traced templates can not provide three dimensional data - only a two dimensional figure could be created with the template. All third dimension components were measured by hand and noted.

Charleston Naval Shipyard decided to use photogrammetry to solve these problems. The photogrammetric specialist had mold loft experience; this proved to be a key factor in correctly determining what data to capture in order to ensure complete and accurate detailed photographs. Some of these targeted key areas provided critical dimensions for locations of all pivot points, foundations, the angles of the sheeves in relation to the head, the location of sheeves on the head, the perimeter of the head, the angle of the trackway and its length, and location of stops. Additionally, the specialist made specific observations, noting additional features to investigate during ultimate data analysis using CAD/CAM.

During the actual photogrammetric survey, the targets were attached to the davits on the critical positions to define major features as described above, and photographs were taken primarily using the convergent method of photogrammetry (Figure 1). A few stereo photographs were also taken to allow dimensioning of smaller details. At this point the photogrammetric process for davit replacement moved off the ship and into the shop.

Back in the shop, the photographs were developed and photogrammetric three dimensional data were extracted from the photographs. These data were then used to produce a CAD/CAM part

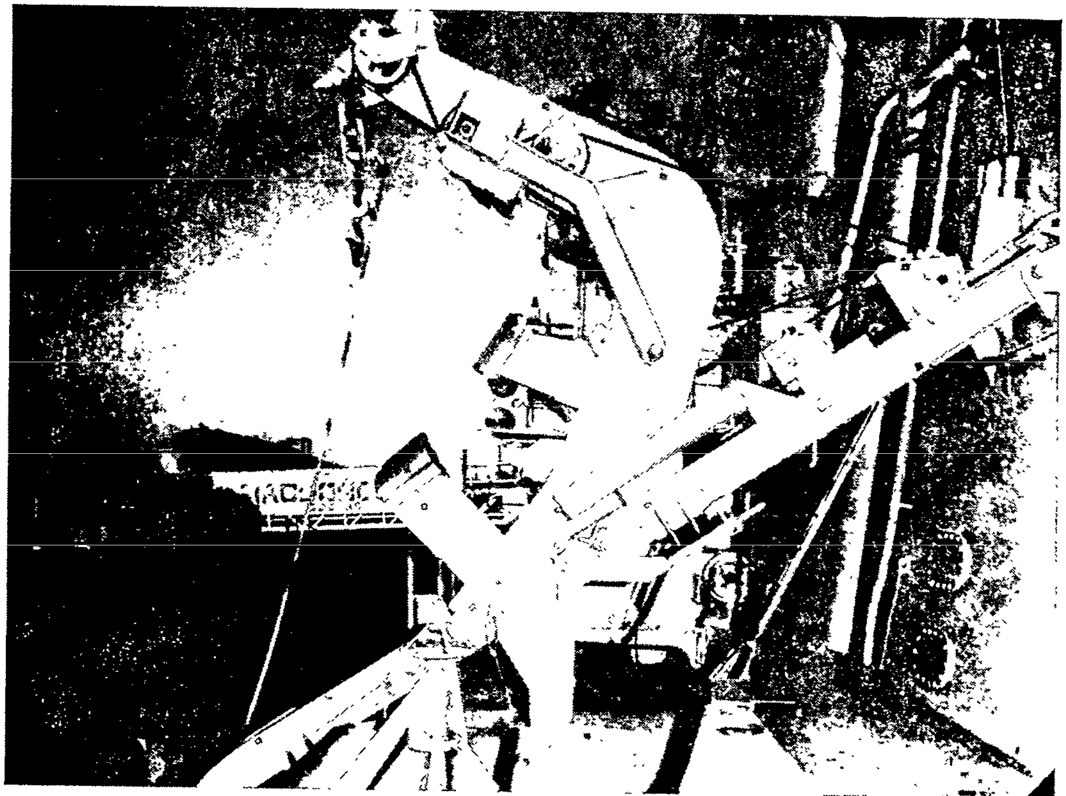


Figure 1. DDG – 639 PERSONNEL BOAT DAVIT (AFT SIDE, LOOKING FORWARD) Note small black and white targets on critical attributes.

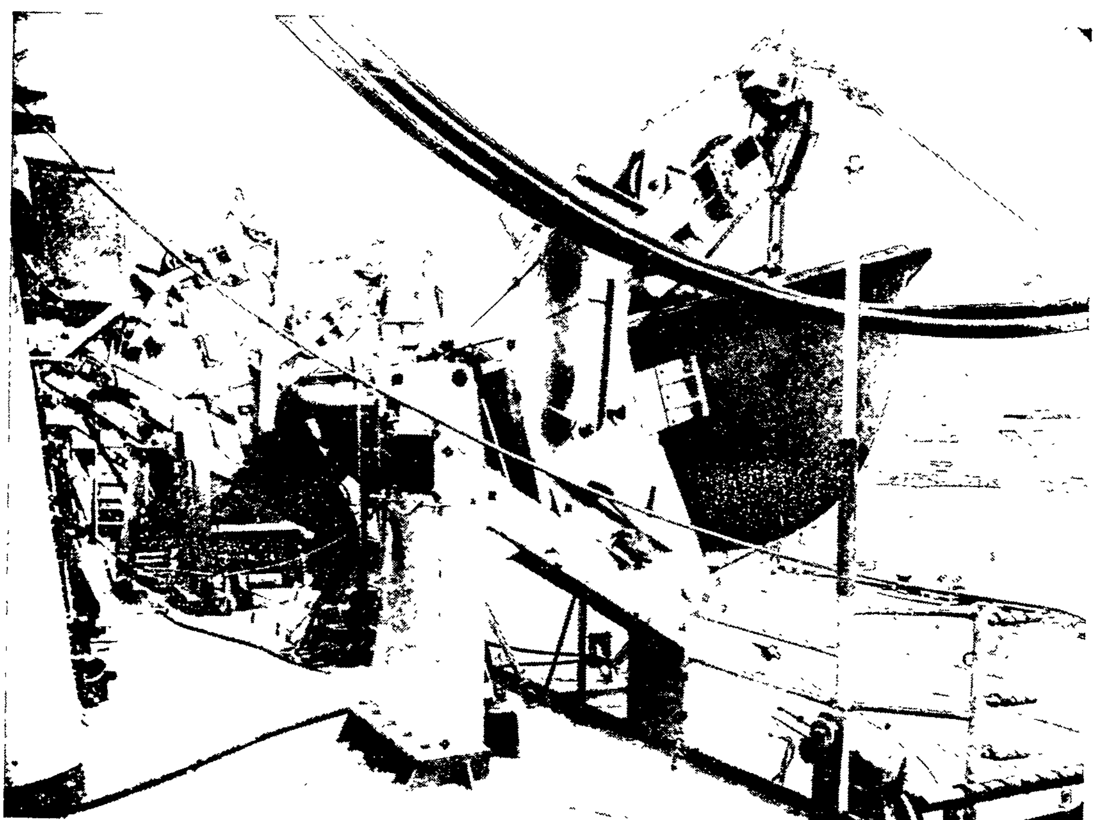


Figure 2. DDG-45 WHALE BOAT DAVIT (FORWARD SIDE. LOOKING AFT) Note targets on critical attributes.

drawing in order to ultimately generate a flat pattern template from the photogrammetry data.

The use of photogrammetry on the development of the whale boat davits was a success. Subsequently, a similar process was employed to create the davits for the DDG-39 personnel boats, with a few changes. The aft side of the head of this davit was found to be completely different from the forward side of the head (Figure 2). Therefore, photographs of both sides of the davit were taken to ensure that all dimensional attributes were captured to recreate the davit. Further, unlike the whale boats which were photographed mostly for convergent analysis, this project was shot primarily in stereo. Although this affords a lesser degree of accuracy (1/32 inch), it also requires fewer targets, and most of the needed data can be extracted from the pictures without targets.

Both of the davits projects were successes. Rework was avoided because measurement methods increased the accuracy of the templates; using photogrammetry eliminated the cumbersome, time-consuming old method. Finally, mechanics were able to recreate the new davits while the ship was gone, and without removing and bringing an old davit into the shop. When the boat returned, the new davits were installed, allowing the ship to remain operational throughout the process. Therefore, Charleston Naval Shipyard succeeded in effectively employing photogrammetry as a tool in dimentional attribute determination.

PHOTOGRAMMETRIC HULL CIRCULARITY MEASUREMENTS

Recognizing the structural verification advantages of photogrammetric technology, Charleston Naval Shipyard has been interested in the application of photogrammetry to hull circularity measurements. With the revision A of MIL-STD-1688 (not yet issued), the optical squares method currently used at Charleston, and some other methods currently employed by other naval shipyards will most likely become obsolete by their inability to meet the accuracy and repeatability requirements the revision will require; photogrammetry, however, can provide up to 1/64 inch to 1/32 inch accuracy, depending on camera stations and the photographic angles. Therefore, Charleston Naval Shipyard initiated a test concurrent with the compartment removal project to verify photogrammetry as a method for measuring full and partial circularities. Based on this test methodology, the Production Industrial Engineering Division at Charleston Naval Shipyard is preparing a process instruction for the use of photogrammetry in measuring hull circularity for all naval shipyards. A clearly defined procedure is necessary in order for the process to be approved by NAVSEA in accordance with the existing MIL-STD, and the upcoming revision.

According to the MIL-STD, circularity measurements are necessary at all hull locations subjected to frame cuts and hull penetrations during ship repair and alteration. The first phase of conducting a photogrammetric hull circularity survey involves planning the job. Major obstructions to the view of the area to be surveyed, such as staging, platforms, or enclosures must be planned to be removed, or the photographs must be shot around the obstructions. All targeted points must appear in at least two photographs, and four to five photographs are recommended "just in case", but singularly missed targets are not a problem and can be easily interpolated to approximately 1/32 inch. Overlapping photograph shots is recommended in order to "tie" adjacent shots together. Specifically, double-faced targets must be included that "connect" the port and starboard side shots.

During set up of the actual photogrammetric survey, circumferential lines perpendicular to the main axis of the hull must be scribed. Targets are placed every five degrees along the line. (For reference, topside is considered 0 degrees, and keel is at 180 degrees). In the keel area between 150-210 degrees, radial offsets of known lengths are used with double faced targets at their endpoints for capturing dimensional data at the keel in both port and starboard shots. Finally an object of known external measurements must be captured in the photographs to establish the scale.

Having planned the shots, and stuck the targets to the hull in the appropriate places, photographs are taken using photogrammetric cameras from planned stations, including overhead shots from zero degrees using an overhead crane. Because the convergent method is preferred for photogrammetry, multiple shots of the area in question from various angles are required for accurate triangulation.

Once the pictures are developed, the original negatives are measured.

Two dimensional photomeasurements are turned into three dimensional coordinates of the targets via software designed to perform photogrammetric triangulation. The raw data coordinates corresponding to each target, input to a CAD system, are developed into a mean circle which is then compared to the actual expected contour. Deviations are calculated every five degrees and a best fit circle is developed in order to determine the measured circularity of the hull (Figure 3).

Photogrammetry, as applied to structural verification, particularly in the case of hull circularity measurement, will greatly benefit the naval shipyards by replacing the obsolete methods, which are generally very labor intensive and sometimes suspect in their accuracy, with an advanced, reliable state-of-the-art method of determining a hull's roundness characteristics.

CNSY PRESSURE HULL
POST CIRCULARITY
FWD END 6”AFT FR 59
SSBN 619 INACTIVATION
EACH INCREMENT EQUALS I IN.

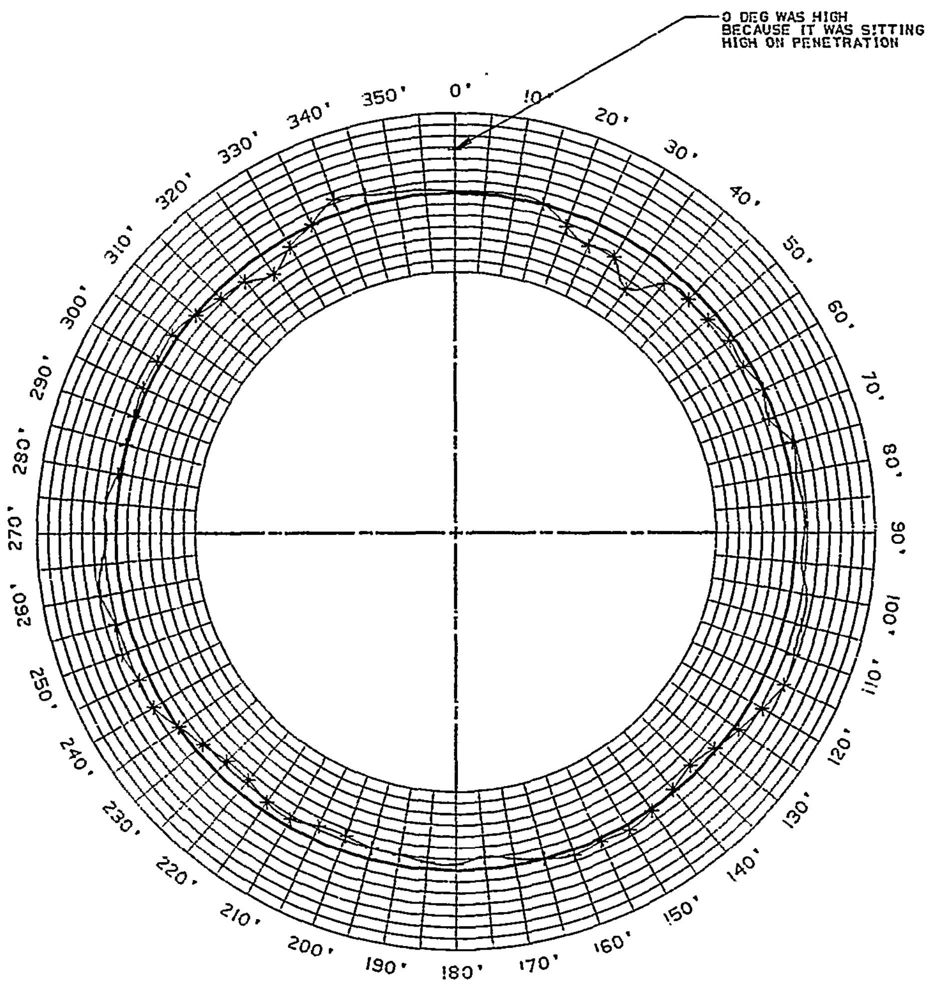


Figure 3. HULL CIRCULARITY CONTOUR PRINTOUT Actual printout **of SSBN 619 circularity 6 inches aft of frame #9 depicts mean hull contour (solid dark line) and actual measured deviation in 0.1**

COMPARTMENT REMOVAL/BULL JOINING

Charleston Naval Shipyard implemented photogrammetric technology on a specific project for the SSBN 619. Charleston Naval Shipyard was required to remove the missile compartment on SSBN 619 in a very short period of time. Charleston Naval Shipyard drydocked SSBN 619 and removed the compartment nearly two to three weeks ahead of schedule. In this case, Charleston employed photogrammetry as an advanced planning tool.

On previous jobs of this nature using traditional methods, after the' rough cuts had been made and the compartment removed, the exposed aft and fore ends were pulled to within 12 inches of one another. Each end was then manually measured, compared to the other, and cut iteratively until the fore and aft ends matched. at which time a final pull was made to join the two ends for welding. This method was very labor intensive, posed a great fire risk, and required rework as the process methodology.

Charleston Naval Shipyard proposed to use photogrammetry to eliminate the need to manually rework each end until a match was achieved, and to reduce the entire operation to a single pull to join the two ends together.- The method is outlined as follows:

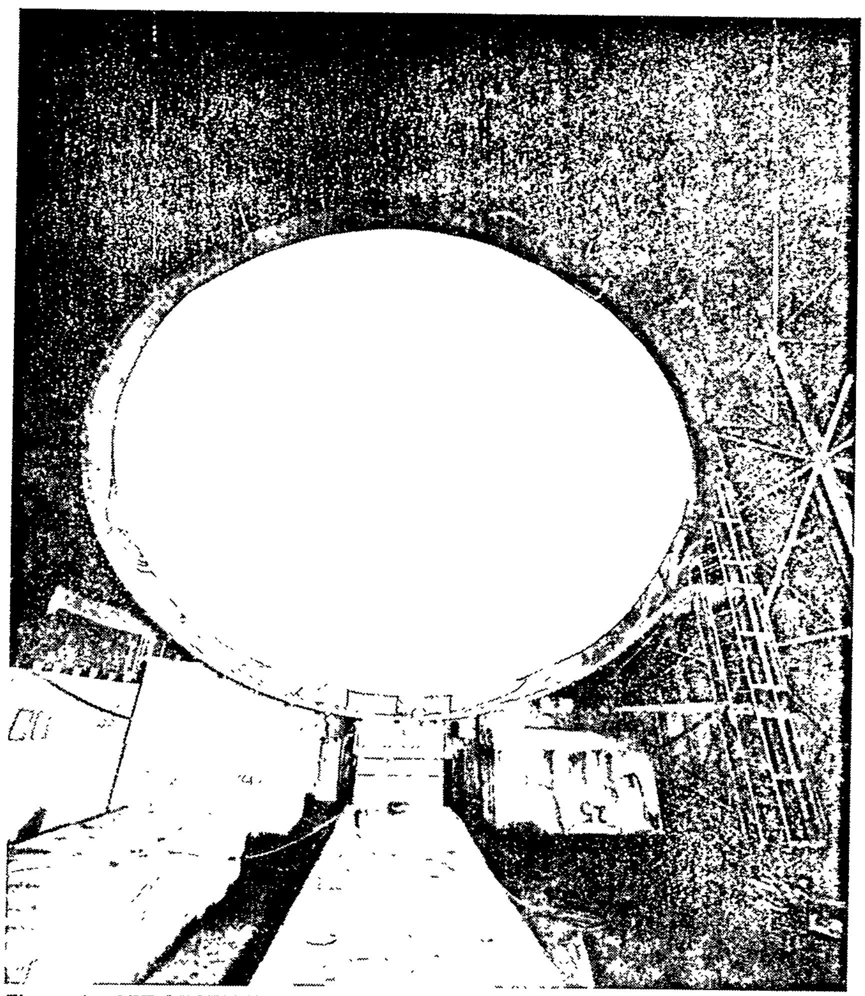


Figure 4. AFT SECTION SSBN 619 AFTER MISSILE COMPARTMENT REMOVAL

Sketch depicts aft exposed end after removal of missile compartment.
Note placement of photogrammetric targets along the mating face.

Shipwrights began by scribing lines about the hull to mark the initial cuts. The missile compartment was rough cut out in segments. As soon as the aft end was exposed, welders trimmed neatly to the scribed line and weld prepped. A photogrammetric survey was subsequently made of both the aft (prepped) and forward (unprepped) surfaces, with targets every 2 1/2 degrees on each end. (Figure 4) The data from the survey, entered on CAD/CAM, was compared and a template that matched the prepped surface was developed for the unprepped surface. Once the unprepped surface was cut to the prescribed dimensions, it was expected that one pull would be sufficient to join the surfaces for welding.

The Structural Group at Charleston Naval Shipyard attempted to eliminate the second pull required to join two hull halves using a traditional method by changing the method to include photogrammetry. Although this first attempt did not result in a single pull as anticipated, this initial experience in joining hull halves using photogrammetry has provided valuable lessons learned. Analysis of the hull fit indicated up to 1 13/16 inch deviation at the worst point (only 1/4 inch is allowable for welding). Problems were attributed to the following:

During photogrammetric measurements, analysts assumed that shipwrights reference lines were accurate; it was not emphasized that scribed line accuracy should be no less than +/- 1/8 inch. The reference lines were adequate for hull circularity measurements, but not accurate enough for the fit-up application. One scribed line followed a weld-butt on the hull that dog-legged near the top around an obstruction, creating a marked difference on port and starboard sides. This caused the cuts to be angled (0.3 degrees on starboard side and 0.1 degree on port side. Average 0.2 degrees = 1 1/2 inch deviation) These minute angles were not detected during the photogrammetric analysis, but could have been if a reference line, common to both halves, had been established during the planning phase. Further, there was no monitoring of ship's changing structural conditions to determine shift of ship after cut. (The impact of this issue is not known.)

Structural group personnel analyzed the situation and developed two important corrections to the procedure that must be established in order to ensure future successes. First, scribed reference lines must be assuredly shot to an accuracy of +/- 1/8 inch. The lead shop will properly inform assist shops of this requirement. Second, and most importantly, a reference line, common to both halves, must be established in the photogrammetric shots in order to determine if any deviation exists. Because of the accuracy provided by photogrammetry, even small deviations can be detected if this reference line exists on the photographs - regardless of the location, the sums of the angles on the straight line must equal 180 degrees. Different methods may be used to accomplish this, including simulation of the track in place between the two halves, or shooting the photogrammetric data with the track in place.

PHILADELPHIA BOW REPLACEMENT PROJECT

Philadelphia Naval Shipyard used photogrammetry as an advance planning tool in a project slightly different from the compartment removal/hull joining project at Charleston Naval Shipyard. In 1985, during deployment in the Sea of Japan, USS Kitty Hawk (CV-63) was struck by a submerged Soviet submarine, causing significant structural damage to the bow of the ship. An estimated 99.25 tons of concrete were poured into various bow compartments to seal cracks in the hull caused by the collision. This allowed the ship to remain operational until the next scheduled overhaul availability.

Upon USS Kitty Hawk's arrival in Philadelphia Naval Shipyard for a scheduled Service Life Extension Program (SLEP) overhaul, engineers determined that the entire concrete filled damaged bow section would have to be replaced. This included a section 11 feet wide, 11 feet high, affecting 5 frames forward to aft approximately 21 feet (Figure 5). This section was cut from the ship and removed, and Philadelphia Naval Shipyard was faced with fabricating a replacement bow.

The Philadelphia Naval Shipyard Zone Technology Office chose photogrammetry as the preferred method for determining the dimensions necessary to construct the replacement bow section, and as a measure of ensuring a first-time quality fit-up of the new bow to the ship. This application of photogrammetry as an advance planning tool was a success for Philadelphia Naval Shipyard.

For this project, photogrammetric surveys were performed twice. The first photogrammetric survey was performed on-site 16-18 May 1988. Data were collected at the ship to

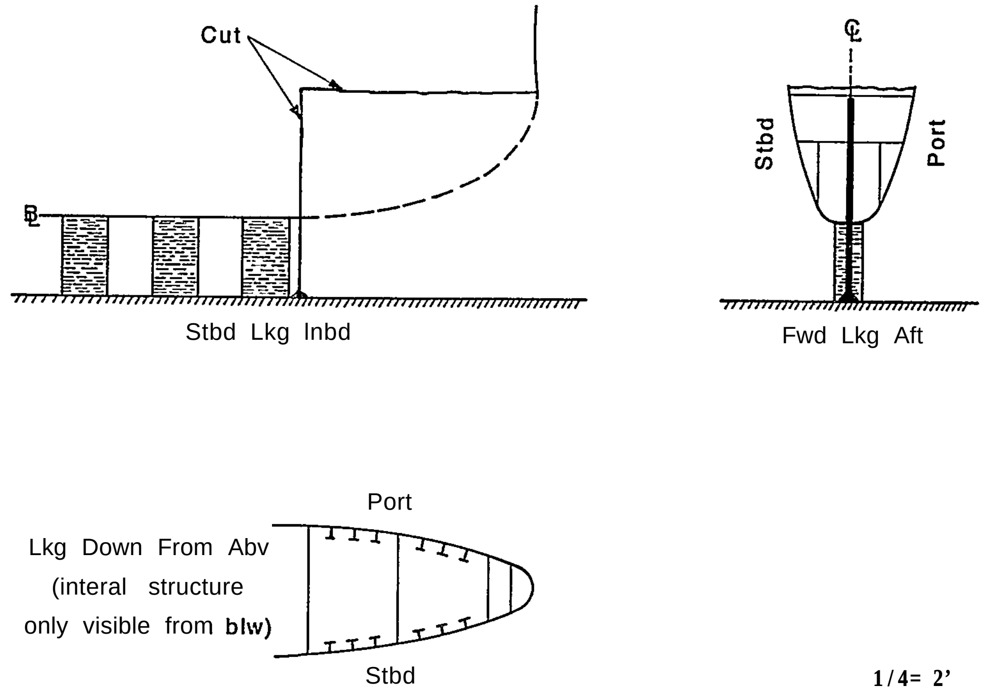


Figure 5. DAMAGED KITTY HAWK BOW SECTION

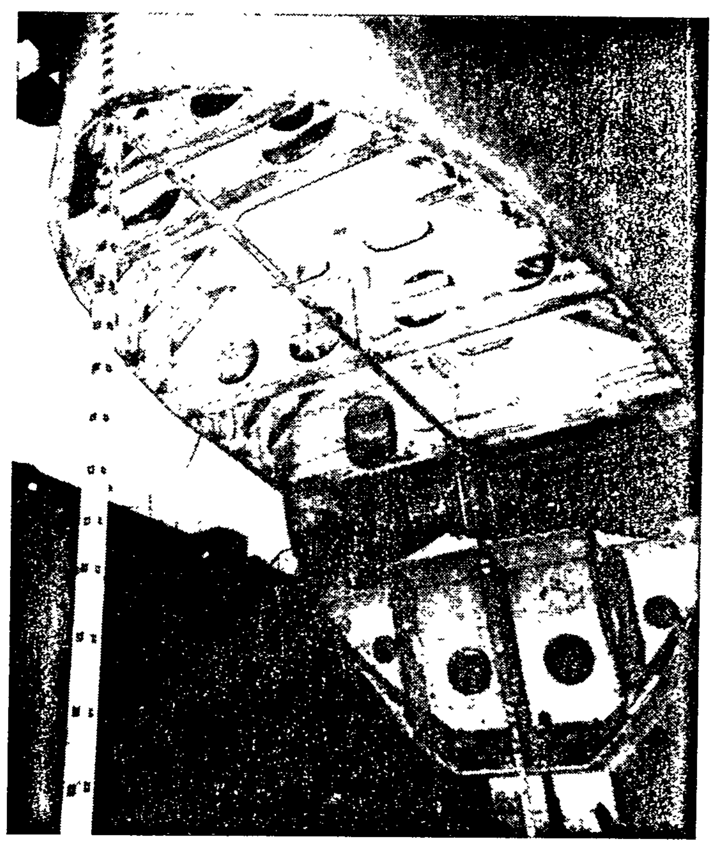


Figure 6. KITTY HAWK WITH BOW CUT AWAY The first of two photogrammetric surveys for the bow project was performed on this section. Note targets along cut lines and reference points.

determine what the dimensions of the mating faces of the replacement bow section should be; the challenge was to fit the perpendicular planes simultaneously (Figure 6). The photogrammetry team targeted structural members, scribed lines, and reference lines: the convergent method was used to capture targets at six inch intervals along the cut lines. The data were extracted from the photographs, translated, and rotated into the ship's coordinate system. The resultant raw data were sent to Philadelphia Naval Shipyard shop 11 mold loft personnel to be converted to graphic format on CAD. The outline of the dimensional attributes of the actual cut out section on the ship was compared to the offsets on the existing as-built drawings. This comparison exposed inconsistencies between the dimensions on the drawings, and the photogrammetric data representing the existing conditions: Philadelphia Naval Shipyard chose to accept-the dimensions as developed using photogrammetry. Thus, based on the photogrammetric data, building changes to bow construction were made.

Large complicated fabrication jobs such as the bow construction which are sometimes subject to small mistakes in workmanship are invariably amplified due to the large size of the overall project. In order to verify that the newly constructed bow would properly mate to the cut away section at the ship, additional photogrammetry of the ship's newly fabricated replacement bow was performed to ensure the first-time correct fit-up and alignment of the replacement bow section to the ship. The second photogrammetric survey was performed 19-20 September 1988 on the newly constructed replacement bow mating faces (Figures 7a and 7b). Resultant data from this survey was compared to the data extracted from the first photogrammetric survey of the actual dimensions of the ship; slight deviations were discovered, and minor in-shop adjustments were made to the replacement bow before fit-up. Finally, the new bow was transported to the ship in drydock. Not surprisingly, the bow fit the ship without requiring rework.

The Kitty Hawk Bow Replacement efforts were not only structurally successful: they also helped to prove the value of photogrammetry, and more importantly, to build the shipyard's confidence in the industrial applications of photogrammetry.

CABLE REEL ASSEMBLY FOUNDATION PROJECT

In order to accommodate a cable reel assembly for new equipment being installed on navy frigates, shipyards were tasked with completely converting what used to be a navy personnel weight room to outfit the SHIPALT. This included installing an 8' x 12' foundation to support the cable reel assembly. Based on experiences learned from a private shipyard that had to rip out the newly installed foundation completely several times and start again because of misalignments, Charleston Naval Shipyard decided to try a new approach: they used photogrammetry to preplan the job.

The challenges in successfully completing this project are threefold: first, the contour of the bottom of the foundation must match deck deformations; second, the top of the foundation must be prepared to accommodate the cable reel assembly; and third, the reel must line up with the fair lead in the ship's hull.

In normal operations, without the benefit of photogrammetry, patternmakers develop a model on CAD/CAM for 'the general specifications of the foundation and generate a pattern from which the shipfitters fabricate the foundation. The prefabricated foundation is then taken to the ship. In the compartment at the ship the foundation is fit to the deck; where it does not fit satisfactorily for welding purposes, it is rigged and raised from the floor to be cut. This process continues until an acceptable match is created between the mating faces of the bottom of the foundation and the deck. The foundation is then welded to the deck. Next, machinists begin the process of machining the top of the foundation to install the assembly with respect to proper alignment with the fair lead.

The process changes considerably using photogrammetry. After patternmakers develop the pattern of the foundation, and while the shipfitters are prefabricating the foundation, a COPY of the pattern is taken to the ship's compartment, and the pattern is center-punched onto the floor. (Figure 8) Photogrammetric targets are placed along the center-punch lines the Water lines, to the fair lead and along all deformations on the deck where the foundation must match to the deck, thus capturing the contours of the floor over weld butts and deck curvatures. After all of the targets are set and numbered for identification, photographs are taken using photogrammetric cameras. The

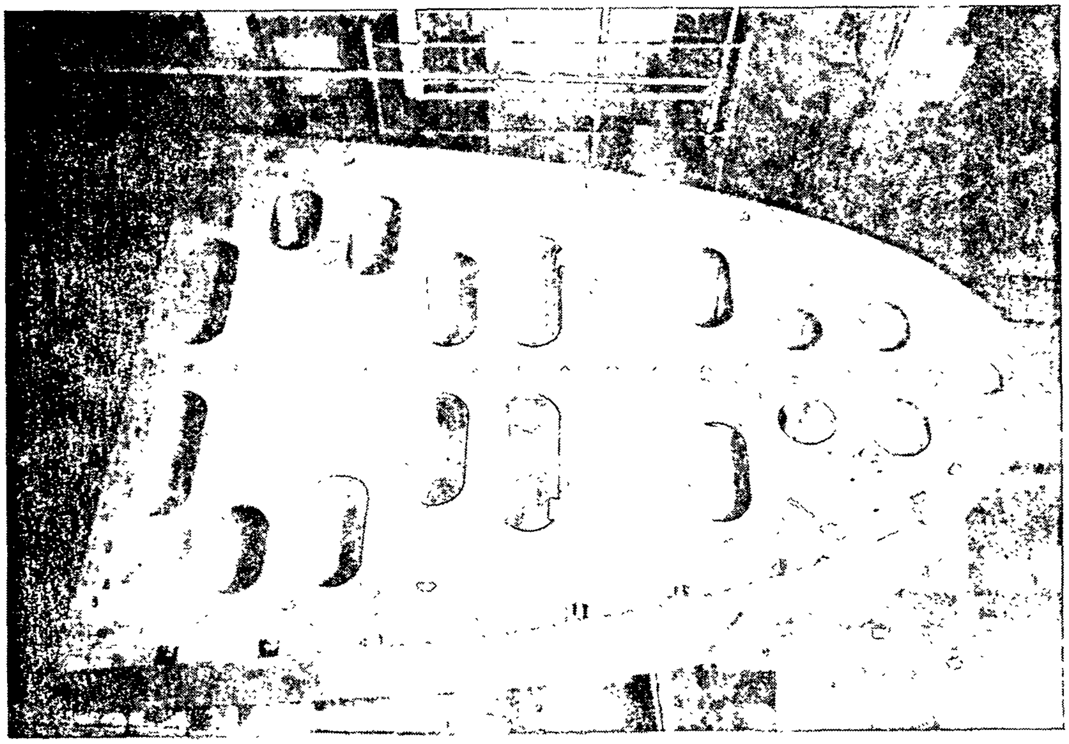
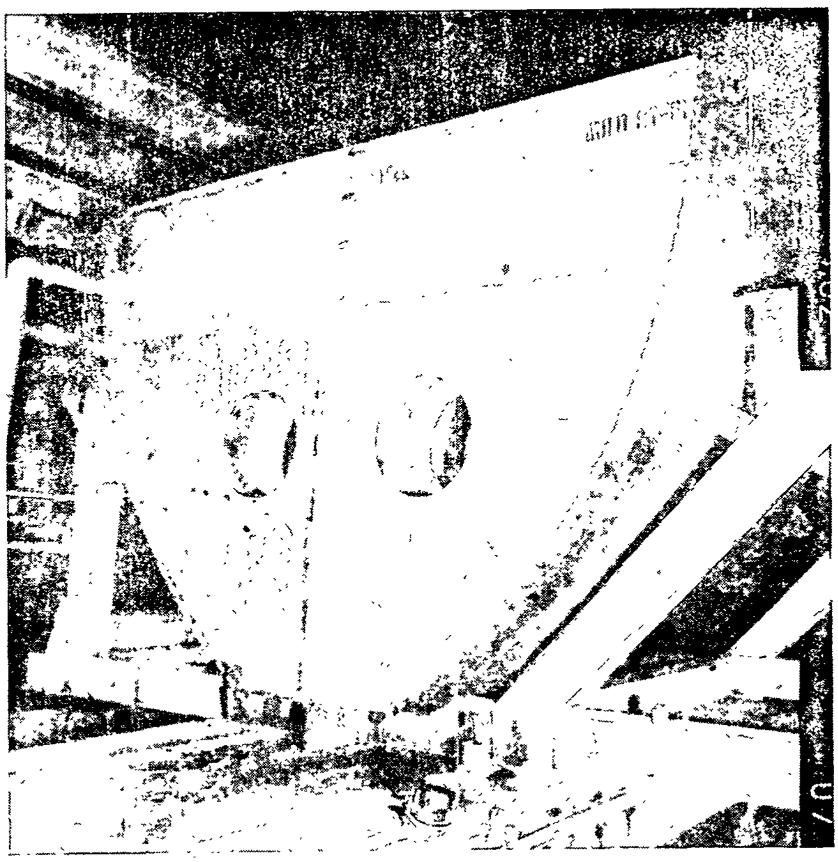


Figure 7a. NEWLY CONSTRUCTED KITTY HAWK BOW (TOP VEIW) The second of **two** photogrammetric surveys for the bow project was performed on new bow section. Note the reference targets used to check the dimensions.



FORWARD)

Figure 7b. NEWLY CONSTRUCTED KITTY HAWK BOW (AFT LOOKING

convergent method of photogrammetry is used, with photographs taken from nine different photostations in the compartment. The set up and photography takes exactly two hours to perform (not including initial targeting performed by the mold loft-personnel). The film is developed immediatelv to determine if all points are captured, and to be sure no shot needs to be retaken. At the photogrammetric workstation, three dimensional data are extracted from the photographs. Charleston Naval Shipyard mold loft personnel modify the original CAD model of the foundation using the three dimensional photogrammetric data. This model is used to develop templates to properly center-punch and machine the foundation in the shop to fit the ship's deck (mating the bottom of the foundation to the deck), to accommodate the cable reel assembly that would be placed on the foundation, and to properly align the entire foundation, and its associated assembly, with the fair lead. This in-shop machining took only two men, two shifts, or 32 manhours, vice 500 manhours allotted for on-board grinding necessary using the conventional method.

After only forty five minutes rigging the completed foundation into the compartment on the FFG-40 (the first such project), it mated perfectly with the deck - no rework or on board machining was necessary. (Figure 9) Further, the alignment deviated only +/- 6 minutes fore to aft, and +/- 3 minutes port to starboard. Finally, the foundation was welded, using control welding in order to discourage heat warping and deformation.

A total of six other shipyards have attempted this process using conventional methods, and each has failed to be within tolerance on the first attempt at fitting; Charleston Naval Shipyard has succeeded the first time on each of three ships using photogrammetry. Photogrammetry eliminates the need for shipboard rigging and machining for fit-up to the deck, and on board machining the top of the foundation to accommodate the assembly. Using the conventional method, costs are estimated at approximately 1531 manhours. The photogrammetric process is estimated at 1082 manhours (including control welding). Therefore, total savings with respect to the operations that were eliminated, and considering the machining and photogrammetric survey added, are conservatively 449 manhours, or about $20990 per ship. These figures do not include the elimination of rework which figured prominently into the cost of the SHIPALT at the other six shipyards; based on the rework data available on

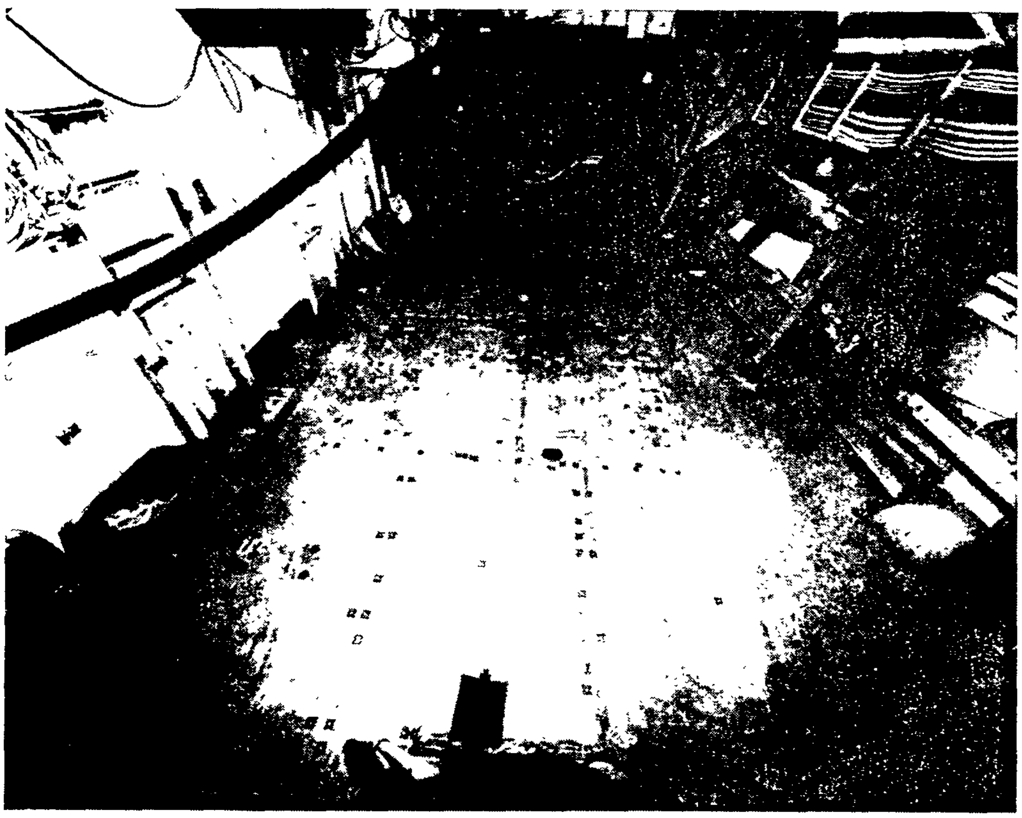


FIGURE 8. TARGET LAYOUT FOR FOUNDATION INSTALLATION PROJECT.

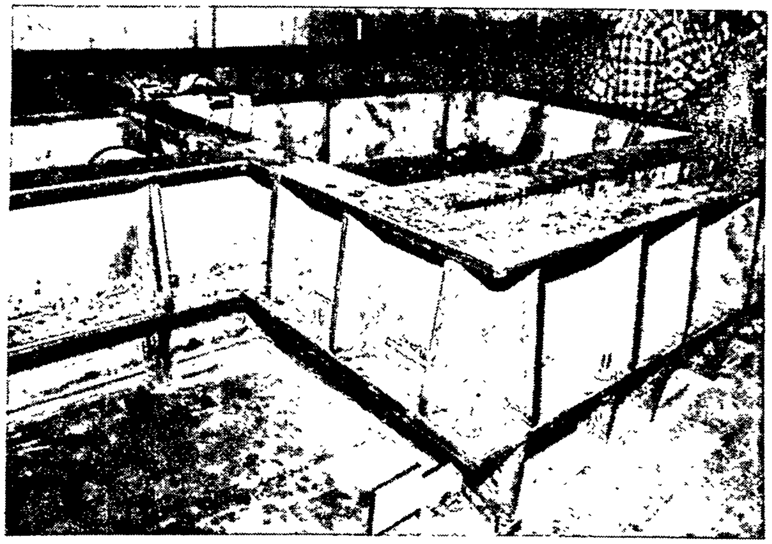
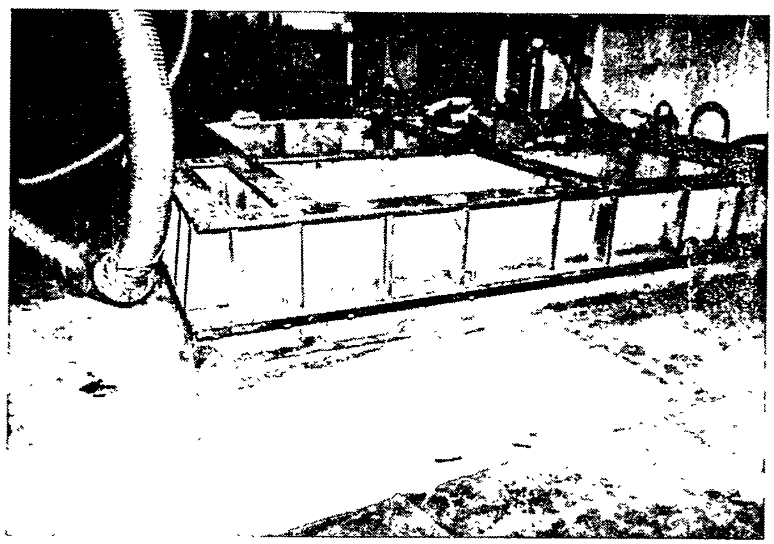


FIGURE 9. (TOP AND BOTTOM) FOUNDATION (WITH STRONGBACK) INSTALLED.



those attempts, it can be estimated that rework time would have been 1.5 times the original manufacturing time, 2297 manhours or $107,385.00 per availability. Charleston Naval Shipyard will complete six such SHIPALTS at a savings, including rework savings, of $770,250.00 for this application.

FAIRING ALTERATION PROJECT

Charleston Naval Shipyard was tasked to perform analteration on USS NARWHAL (SSN 671) such that a fairing enclosure to house equipment would be attached to the topside aft of the hull of the boat. The fairing had an egg-shaped metal framework, and was to be covered with glass reinforced plastic. In this project, the contour, shape, and framework of the fairing must match the surface contour, shape, and taper of the hull, and the frames of the boat. To further confound the problem, Charleston Naval Shipyard was experiencing difficulty in getting a contractor to bid on the installation of the glass reinforced plastic (presumably because the job appeared to be too difficult); the shipyard hoped to entice bidders by offering the completed frame for in shop work rather than for on-site work in the drydock.

Charleston Naval Shipyard decided to use photogrammetry in order to map the conditions of the shell (the

surface contours and shell shape of the hull). The fairing was to cover twenty-eight frames. Thus, photogrammetric targets were placed every 12 inches on the girth of the hull where the fairing intersects the hull along the frame lines and the conical section weld seams. Targets were also placed to establish reference planes. An established waterline formed the horizontal plane used to reference the height; the centerline referenced port and starboard planes, and frame lines referenced fore and aft planes.

Eight photostations were established to capture the data. The photographs were developed and the 3-dimensional data were extracted from the photographs. As with previously discussed projects, the data was entered onto the CAD/CAM system. The mold loft expert made adjustments to the data in order to obtain the "best fit" arc to the data points. Also, the contour of the outboard edges of the fairing that intersect with the hull had to be faired and then developed by the Loft from designed offsets. From the CAD/CAM data, one template was made for each frame structure on the longitudinal fairing, and for the final cut on the supports.

While quality of the alteration is greatly increased using photogrammetry, the greatest savings come in the reduction of manhours, and the reduction in the schedule. This process can be performed conventionally, without the use of photogrammetry, in one of two ways. First, the frames would be constructed in the shop with material left on each frame structure. These frames would be taken to the boat one at a time and cut to fit the shape and taper of the hull and alignment with the previous frame. In the second conventional method, templates would be developed through extensive manual measurements in order to construct the frames in the shop. Both of these methods are extremely labor intensive, and subject to human and process error that results in high rework costs.

Using photogrammetry, the dimensional data is easily obtainable and readily available, eliminating the need for manually creating individual templates; the entire structure can be fabricated in shop, with first time quality, eliminating the need for rework, costly extended rigging services, and on-board grinding. Finally, the structure can be shipped before installation on the boat, with the supporting dimensional data if necessary, to the contractor responsible for adding the glass reinforced plastic, thus assuring lower costs and higher quality on the part of the contractor, and reduced trade interference in the drydock.

SUMMARY

Photogrammetry can be used in a variety of shipyard applications ranging from hull circularity measurements, or assuring the alignment of large compartmental bulkheads, to jobs as small as single component designs, such as valves.

Photogrammetry projects are excellent applications of existing technology. Naval shipyards are recognizing the value of photogrammetry, and are actively encouraging additional naval shipyard personnel to pursue other applications of this technology. Photogrammetry's benefits, both for these and other projects can be shared among all of the naval shipyards with great cost savings potential.

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APPENDIX

Photogrammetric Methods

This paper refers to the use of two different methods of photogrammetry:

1) Convergent Method employs single photographs taken from variously angled positions of the same scene, or of more than one scene tied together with common data points captured in adjacent scenes. Pre-selected targeted data points are computer processed using an xy digitizer and complex triangulation software. The convergent method can easily achieve up to 1/64 inch accuracy for many shipyard applications.

The convergent method affords two to three times greater accuracy than the stereo method. Using the convergent method, there are no restrictions on shot locations or set-up: pictures can be taken from any accessible vantage point. However, unlike the stereo method, targeted data points must be planned before photographs are taken, and only pre-defined, discrete data points can be measured.

2) Stereo Method employs only two photographs of the same scene, or portion thereof, taken from near parallel photoaxes. This method allows free selection of the quantity of data points and the density of detail without preplanning targeted positions. Allows selection of data points after shots are taken using elaborate stereoviewer equipment. The stereo method can achieve up to 1/32 inch accuracy.

Although the stereo method affords a lesser degree of accuracy than the convergent method, it is preferred in situations where the measurement of contours and profiles is necessary, where targetting is difficult or the number of data points is very large. Because the use of this method is constrained by camera placement requirements in order to maintain parallel axes on the two photo shots, its applications in many shipyard industrial Situations may be limited by the presence of physical obstructions in the work environment.

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